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ANALYSIS OF BOLTED-FLANGE JOINT USING FINITE ELEMENT METHOD

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ABSTRACT

Flange Joint is a joint system in the piping system, and is used in almost every industrial sector, the flange joint aims to facilitate checking and maintenance so that it is not permanent. The main concern of the piping engineer on this flange joint is the possibility of leakage that will occur at the joint, this is related to the strength of the material used in the joint. In the flange design process, there are several institutions that regulate flange design standards, for example API (American Petroleum Institute), ASME (American Society of Mechanical Engineers), etc. In this study, there are 3 main objectives, knowing the internal pressure limits of the API 6BX Flange design size 4 1/16 in, knowing the response of joint components to additional external loads combined with internal pressure loads, and knowing the effect of preload variations applied between API and ASME standards. From the simulation results obtained under internal pressure loading, the acceptable limit for the flange joint is 206,8 MPa (30 ksi), where failure is in the flange component which has exceeded the specified yield strength limit of AISI 4130 material (517 MPa). While in the combined loading of internal pressure and external force (44,4 kN, 133,4 kN, 266,8 kN), the maximum stress on the flange component is ±308,92 MPa (API Preload), and ±399,53 MPa (ASME Preload), and bolts. The maximum stress that occurs is ±567,5 MPa (API Preload), and ±593,1 MPa (ASME Preload). These values are still below the yield strength of the material flange and bolt components.

KEYWORDS: Flange Joint, API, ASME & Preload

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Original Article

INTRODUCTION

The bolted-flange joint is one part of the piping system, the main function of the bolted-flange joint is to connect one piping component to other components, for example pipes, valves, pressure vessels, etc. It can be estimated at a medium-sized refinery, there are at least 100.000 bolted-flange joints, because bolted flange joints are not permanent or can be removed when needed, and the potential for leaks in the joint is an important aspect that needs to be calculated. [1].

In this study the problem is solved using the finite element method (FEM), the basic concept of the finite element method is the discretization process, which is to divide the system to be analyzed into smaller parts or commonly called elements. [2]. Finite element analysis is one of the important aspects in designing a product, especially in the product design phase because it saves time and cost for making physical prototypes for testing, so that experiments with different configurations can be carried out repeatedly without having to create a new prototype every time you do a test. [2]

In this bolted-flange joint analysis, finite element analysis is used to test the response of the bolted-flange joint to a predetermined load, such as bolt tightening load, internal pressure, and external load. The static loading

carried out consists of several stages, ranging from single loads to combined loads. Bolted-flange joint model refers to API 6A book, with 6BX series flange 4 1/16 in bore size and 10,000 psi operating pressure.

The output of the flange loading simulation carried out on the Ansys Structural software is to know the value of the stress contained in the flange due to internal pressure on the bolt tightening load, whether the flange material used meets the criteria according to the API 6A standard.

Bolted-flange joint is a joint system in the piping system, bolted-flange joint has been used in every industrial sector such as chemical plants, power plants, oil and gas refineries, etc., bolted-flange joints are used because they are not permanent, making it easier to perform checks and maintenance on piping components [3], simply bolted-flange joint consists of 3 parts, flange, bolt and nut, and gasket.

METHOD

Flange Joint Modeling

The geometry of the flange model is designed based on the API 6A document in the Annex E section, Table E.4, along with the 4 1/16 in 10.000 psi flange model. Can be seen in the figure 1 below.

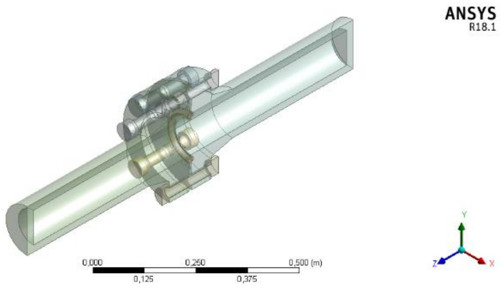


Figure 1: Flange Joint Modeling.

Pre- Simulation

In this research, the geometry file is converted from Solidworks format to Parasolid format, and then I input it in the ansys software. Figure 2 below describes the relationship between the model element values and the resulting stress error, the more elements used the more accurate the results but the analysis time takes a long time.

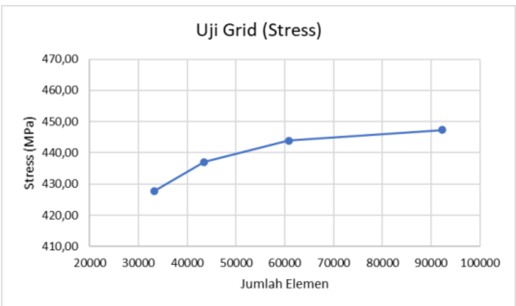


Figure 2: Grid Indepence.

Table 1 below is the list of material used for the model and material properties for each part of Model.

Table 1: Flange Joint Material Properties.

Flange Material (AISI 4130)

Modulus Elasticity (E)	204,7 GPa
Density	7,85 gr/cm^3
Poisson Ratio	0,3
Yield Strength (Sy)	517 Mpa
Ultimate Tensile Strength (Su)	655 MPa
Elongation	18 %

Gasket Material (SS 316)

Modulus Elasticity (E)	193,05 GPa
Density	7,85 gr/cm^3
Poisson Ratio	0,39
Yield Strength (Sy)	290,2 MPa
Ultimate Tensile Strength (Su)	579,8 MPa
Elongation	40 %

Bolt Material (ASTM A193)

Modulus Elasticity (E)	204,7 GPa
Density	7,85 gr/cm^3
Poisson Ratio	0,3
Yield Strength (Sy)	723,9 MPa
Ultimate Tensile Strength (Su)	861,8 MPa
Elongation	16 %

Simulation Set-Up

The operating loading conditions applied in this simulation are divided into 2, the first is a simulation with internal pressure only, with variations in internal pressure as shown in the table below, and second, a simulation with a combined loading of 68.9 MPa internal pressure, and external forces with variations as shown in table 2 and figure 3 (for internal loading simulation), and table 3 and figure 4 (for combine loading simulation)

1.1. Internal Loading Simulation

Table 2: Pembebanan Internal

No	Loading	Type of Loading	Value
1	Bolt Preload	Preload	F = 184,6 kN (API)
2	Internal Loading	Internal Pressure	P = 68,9 Mpa – 275,8 MPa (10 ksi – 40 ksi)

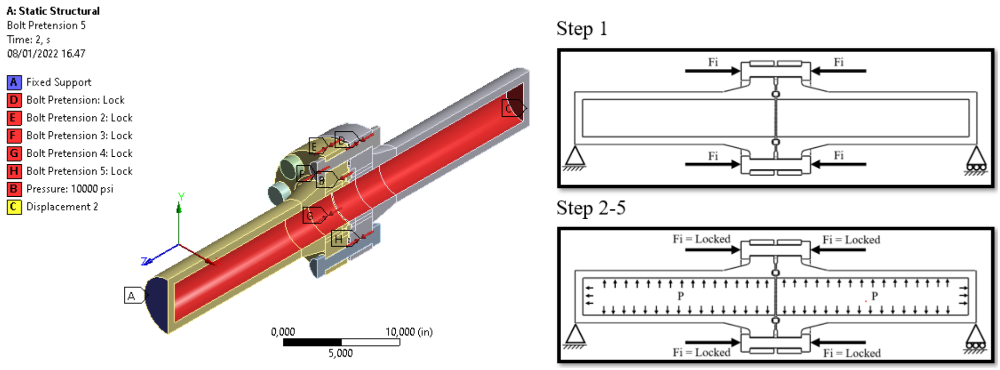


Figure 3: Internal Loading set-up.

2. Combine Loading Simulation

Table 3: Combine Loading

No	Loading	Type of Loading	Value
1	Bolt Preload	Preload	F = 184,6 kN (API) F = 223,1 kN (ASME)
2	Internal Loading	Internal Pressure	P = 68,9 Mpa (10 ksi)
3	Combine Loading	Internal Pressure + External Load	P = 68,9 Mpa + EL (44,4 kN, 133,4 kN, 266,8 kN)

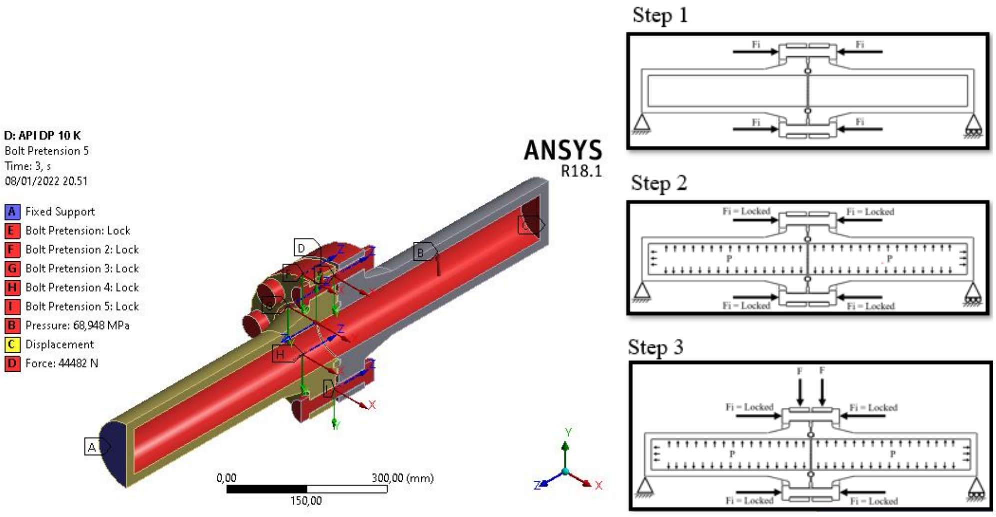
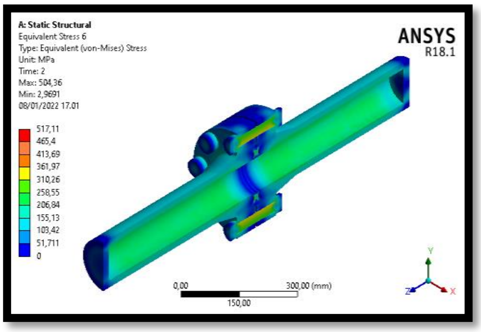


Figure 4: Combine Loading set-up.

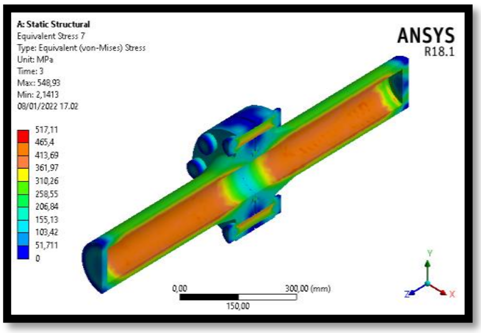
After the simulation set-up, then it can be continued with running analysis on Ansys static structural.

RESULT AND DISCUSSION

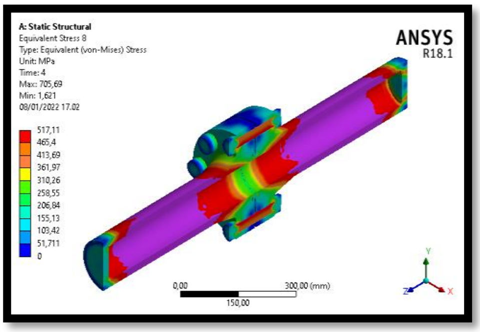
In internal loading simulations, with variations in internal pressure from 68,9 MPa – 275,8 MPa (10 ksi – 40 ksi), but in its application, the ansys software can run simulations up to 206,8 MPa (30 ksi), because above that, the components at the flange connection have exceeded the ultimate strength value of the material used as shown as figure 5, in conclusion the simulation fail to reach convergence criterion above 30 ksi.



(a) 68,9 MPa



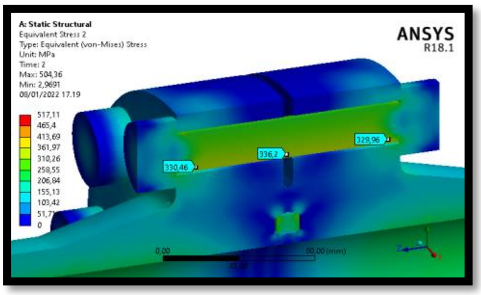
(b) 137,9 MPa

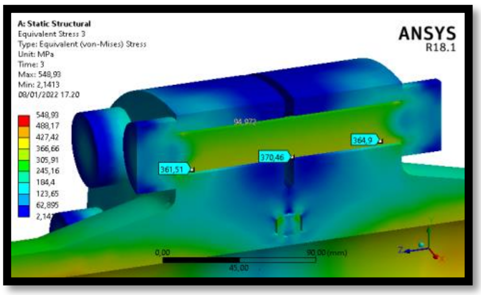


(c) 206,8 Mpa

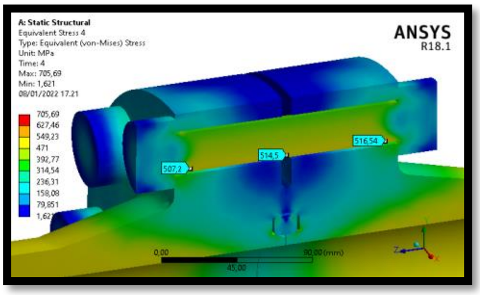
Figure 5: Stress at Internal Loading Flange Connection.

The following plots the stress on the bolt components that occur under internal pressure loading.





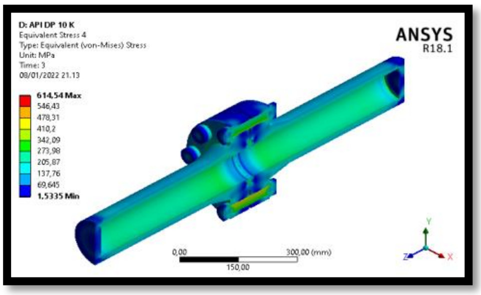
(a) 68,9 MPa **(b) 137,9 MPa**

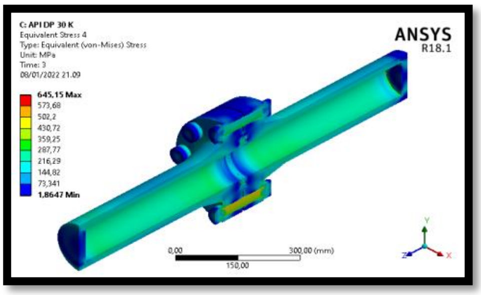


(c) 206,8 Mpa

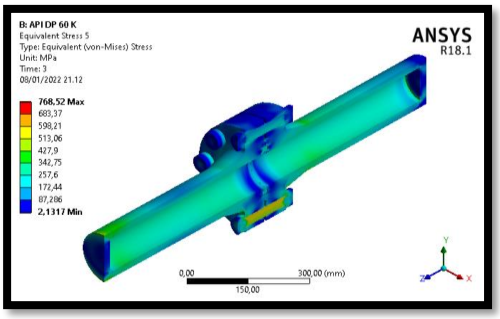
Figure 6: Stress on Bolt under Internal Loading.

In the shank bolt stress plot as shown as figure 6, the internal pressure loading conditions, both at 68.9 MPa, 137.9 MPa, 206.8 MPa, the value of the stress on the shank bolt is still below the yield strength of the bolt material (723.9 MPa), so under internal pressure loading, the bolt can still work effectively.





(a) 44,4 kN **(b) 133,4 kN**

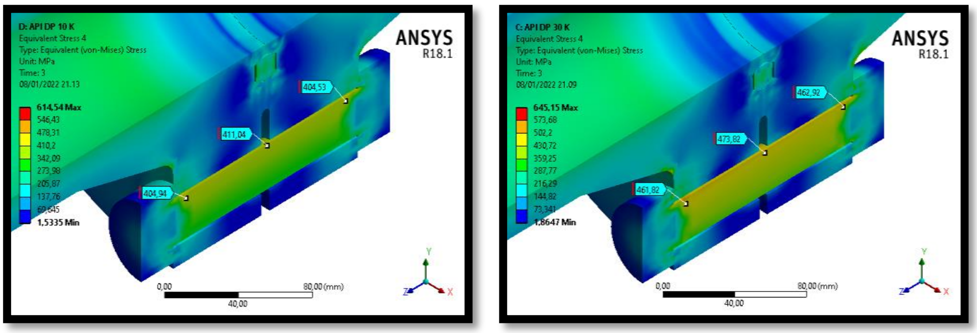


(c) 266,8 kN

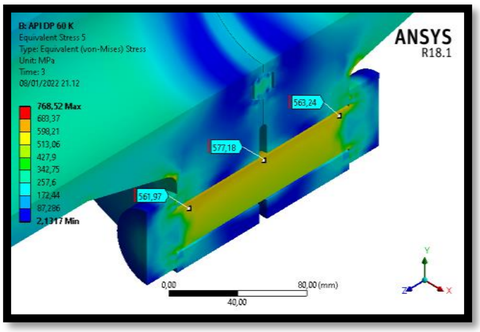
Figure 7: Stress on Flange Joint under Combined Loading.

Figure 7 describes the combined loading simulation, the applied internal pressure value is 68,9 MPa (10 ksi), according to the standard operating pressure of the API 6A 4 1/16 in flange, the external load applied to the joint is the external force that can be seen in the sub- In the pre-simulation chapter, the value of the external force varies, namely, 44,4 kN, 133,4 kN, 266,8 kN, following the results of the stress plot at the flange connection.

There is a significant difference in the stress on the bolt during combined loading, can be seen on figure 8 (API preload) and figure 9 (ASME preload), with the critical zone of the shank section at the bottom of the bolt in the y-axis direction, maximum when internal loading and 266,8 kN external force are ±567,5 MPa (API Preload), and ±593,1 MPa (ASME Preload), but still below the flange material yield strength point (723,9 MPa).

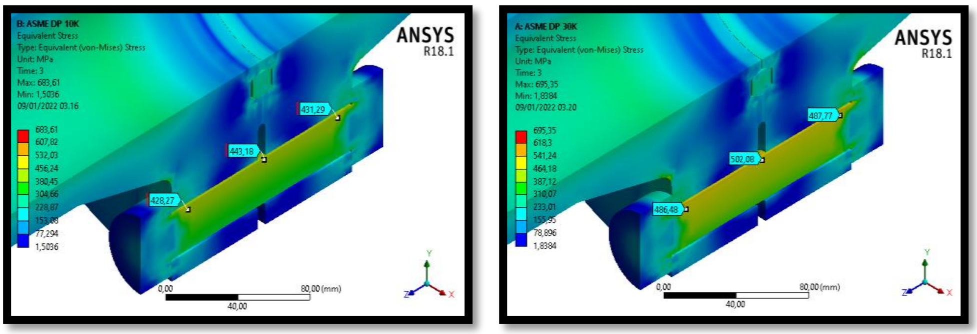


(a) 44,4 kN (b) 133,4 kN

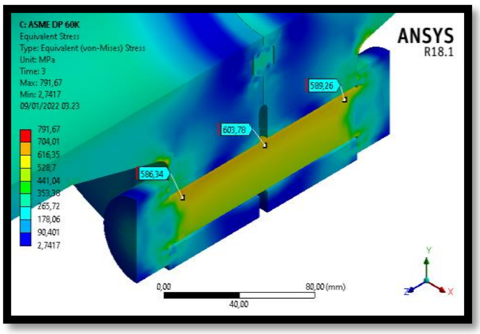


(c) 266,8 kN

Figure 8: Stress on Bolt under Combine Loading (API Preload).



(a) 44,4 kN **(b) 133,4 kN**



(c) 266,8 kN

Figure 9: Stress on Bolt under Combine Loading (ASME Preload).

Figure 10 and table 4 shows the plot of combine loading stress plot with loading variation that has been described previously, the maximum bolt stress is occurred on combine loading internal pressure with external force (266,8 kN).

Table 4: Combined Loading Bolt Stress Plot

	API (MPa)	ASME (MPa)
Preload	334,6	404,7
IP	374,8	421,9
IP+ EL 1	406,8	434,2
IP+ EL 2	466,2	492,4
IP+ EL 3	567,5	593,1

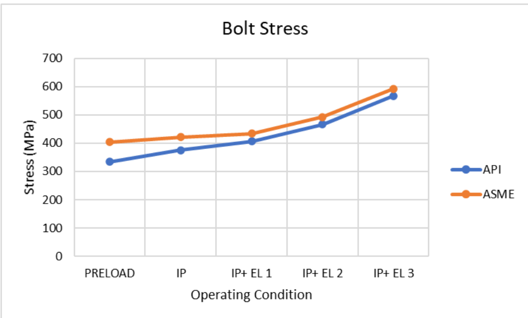
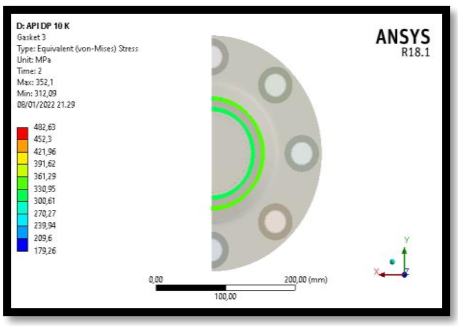
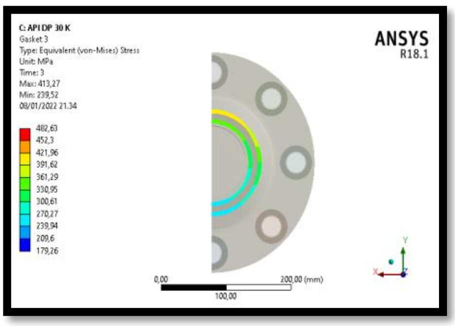
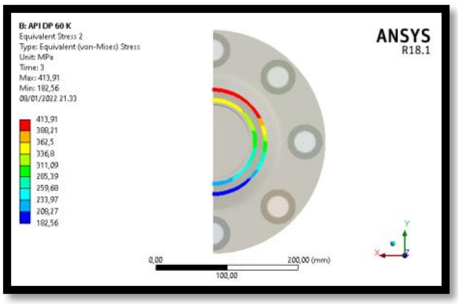


Figure 10: Combined Loading Bolt Stress Chart.





(a) 44,4 kN **(b) 133,4 kN**

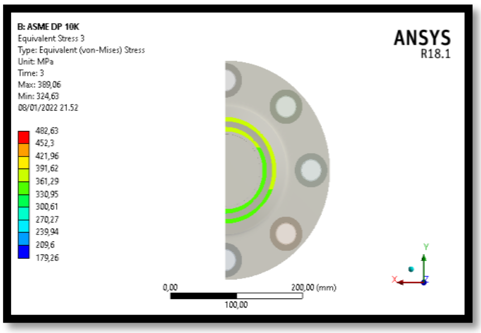


(c) 266,8 kN

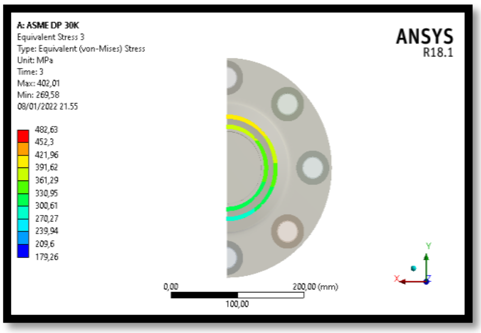
Figure 11: Gasket Contact Stress on Combined Loading (API Preload).

The plot above as shown as figure 11 is the contact stress on the gasket with ASME preload (223,1 kN),There is a significant difference in the stress on the gasket during combined loading, with the critical zone of the gasket contact with the lowest flange in the y-axis direction, the minimum contact stress occurring during internal loading and 266.8 kN external force, which is ±182.6 MPa (API Preload), and ±206.7 MPa (ASME Preload).

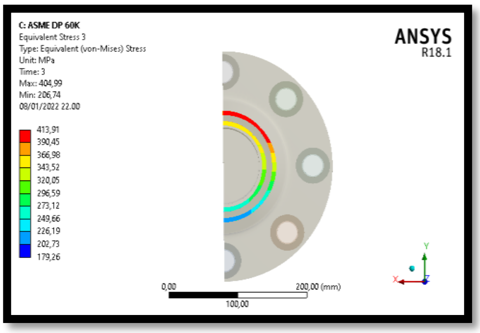
Figure 12 below is the contact stress on a gasket with an API preload (184.6 kN).



(a) 44,4 kN



(b) 133,4 kN



(c) 266,8 kN

Figure 12: Gasket Contact Stress on Combined Loading (ASME Preload).

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Figure 13 and table 5 below is a complete plot of the gasket contact stress under combined loading condition.

Table 5: Combination Loading Gasket Contact Stress Plot

	API (MPa)	ASME (MPa)
Preload	368,2	402,8
IP	314,5	346,8
IP+ EL 1	312,1	324,6
IP+ EL 2	239,2	269,6
IP+ EL 3	182,6	206,7

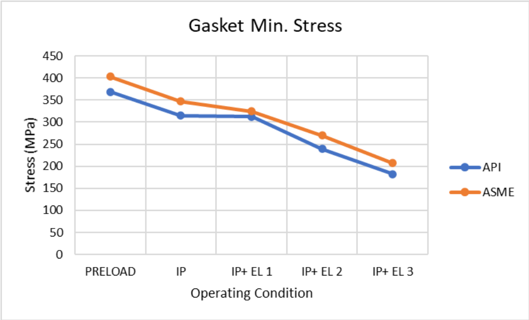

Figure 12: Gasket Contact Stress on Combined Loading (ASME Preload).

Previously it was known the stress that occurred in each component of the flange connection in each loading condition, and the value of the stress used was the von-mises stress, according to Juvinall (2008), when determining the safety factor or failure criteria, the theory of maximum energy distortion (maximum distortion-energy theory) is recommended to be used because the material used in flange components tends to be ductile (yield), the following tables 6, 7, and 9 will show the safety factor of each component as plotted in the previous sub-chapter.

Table 6: Safety Factor of Internal Pressure Loading Components

Operating Condition	Safety factor		
	Flange	Bolt	Gasket
68,9 Mpa	2,9	2,1	1,12
137,9 Mpa	1,4	1,9	1,2
206,8 Mpa	0,9	1,4	1,4

Table 7: Combined Loading Component Safety Factor (Preload API)

Operating Condition (API)	Safety factor		
	Flange	Bolt	Gasket
44,4 kN	2,3	1,7	0,8
133,4 kN	2,2	1,5	0,702
266,8 kN	2,1	1,2	0,701

Table 8: Combined Loading Component Safety Factor (ASME Preload)

Operating Condition (ASME)	Safety factor		
	Flange	Bolt	Gasket
44,4 kN	2,9	2,1	1,12
133,4 kN	1,4	1,9	1,2
266,8 kN	0,9	1,4	1,4

At a glance, in table 6, 7, and 8 the safety factor value of the gasket under combined loading has been below 1, which means that the object has entered the plastic deformation phase, but it should be underlined that the gasket component is a disposable component that acts as a sealer on the connection, so further studies are needed on how much safety is ideal factor specifically for gasket components because in the simulation above, the flange and gasket components are still in contact, which indicates that there has not been a leak.

CONCLUSIONS

From the results of research that has been carried out, the following results are obtained:

In the simulation with loading only using internal pressure, with the aim of knowing the internal pressure limit that can be held by the flange connection, the highest stress is found at the connection between the flange and pipe components with the von Mises stress value already exceeding the yield strength of the flange and pipe material (517 MPa), this simulation stops convergent at a loading of 277,5 MPa, because there are components in the connection that have reached the ultimate strength of the flange material (655 MPa).

The stress on the bolt under internal pressure variation is the highest when the internal pressure is 206,8 MPa, which is ±512,74 MPa, while the yield strength of the bolt material is 723,9 MPa, so it is still considered safe because no plastic deformation has occurred. Meanwhile for gaskets, the stress on the gasket tends to decrease as the internal pressure increases, at a pressure of 206,8 MPa, the stress on the gasket is ±203 MPa.

In the load simulation of the combination of internal pressure (68,9 MPa) and external force (44,4 kN, 133,4 kN, 266,8 kN), the stress on the flange is at the bottom fillet hub in the y-axis direction, maximum when internal loading and 266,8 kN external force, namely ±308,92 MPa (API Preload), and ±399,53 MPa (ASME Preload), but still below the yield strength point of the flange material (517 MPa).

There is a significant difference in the stresses on the bolts under combined loading, with the critical zone of the shank section at the bottom of the bolt in the y-axis direction, maximum when internal loading and 266.8 kN external force are ±567.5 MPa (API Preload), and ±593.1 MPa (ASME Preload), but still below the flange material yield strength point (723.9 MPa).

There is a significant difference in the stress on the gasket during combined loading, with the critical zone of the gasket contact with the lowest flange in the y-axis direction, the minimum contact stress occurring during internal loading and 266,8 kN external force, which is ±182,6 MPa (API Preload), and ±206,7 MPa (ASME Preload).

From the results above, it can be seen that the effect of the preload difference given during the bolt tightening process, on the flange and bolt stresses, the higher stress value when preloading uses the value of the ASME reference (223.1 kN), so care must be taken that the material used does not exceed the yield value. strength of the material used, and at the gasket contact stress, the minimum contact stress value is higher, so the connection is tighter than using the API reference preload (184.6 kN).

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